"FAR TERM VISIONS"

--not really, actually mid-to-longer term possibilities which are "different," require/offer new design paradigms and revolutionary performance improvements

"THE FRONTIERS OF THE RESPONSIBLY IMAGINABLE"

Dennis M. Bushnell

Senior (Chief) Scientist

NASA-Langley Research Center

ELEMENTS OF THE LONGER TERM PROBLEMS IN CIVIL AVIATION

- **Economics/economic warfare**
  - **Aircraft cost/efficiency/productivity**
  - **Airport/runway productivity**
- **Enhanced demand**

including additional constraints/consideration of

- **Energy conservation**
- **Emissions**
- **Noise**
- **Safety**

STATUS OF U.S. CIVILIAN AVIATION INDUSTRY

CURRENT

- Largest single source of positive trade balance (0[$20 to 40B/yr])

TRENDS

- Loss of 0 (30+%) market share within last approximately 5 years to airbus industry
- Largest single aerospace and airline systems (Russian/ Aeroflot) becoming players in western civilian aeronautics
- Airbus very agressive re: technology; e.g.,
  - Composite materials
  - Side stick controller
  - Glass cockpit
  - Excellent wing/hi lift performance

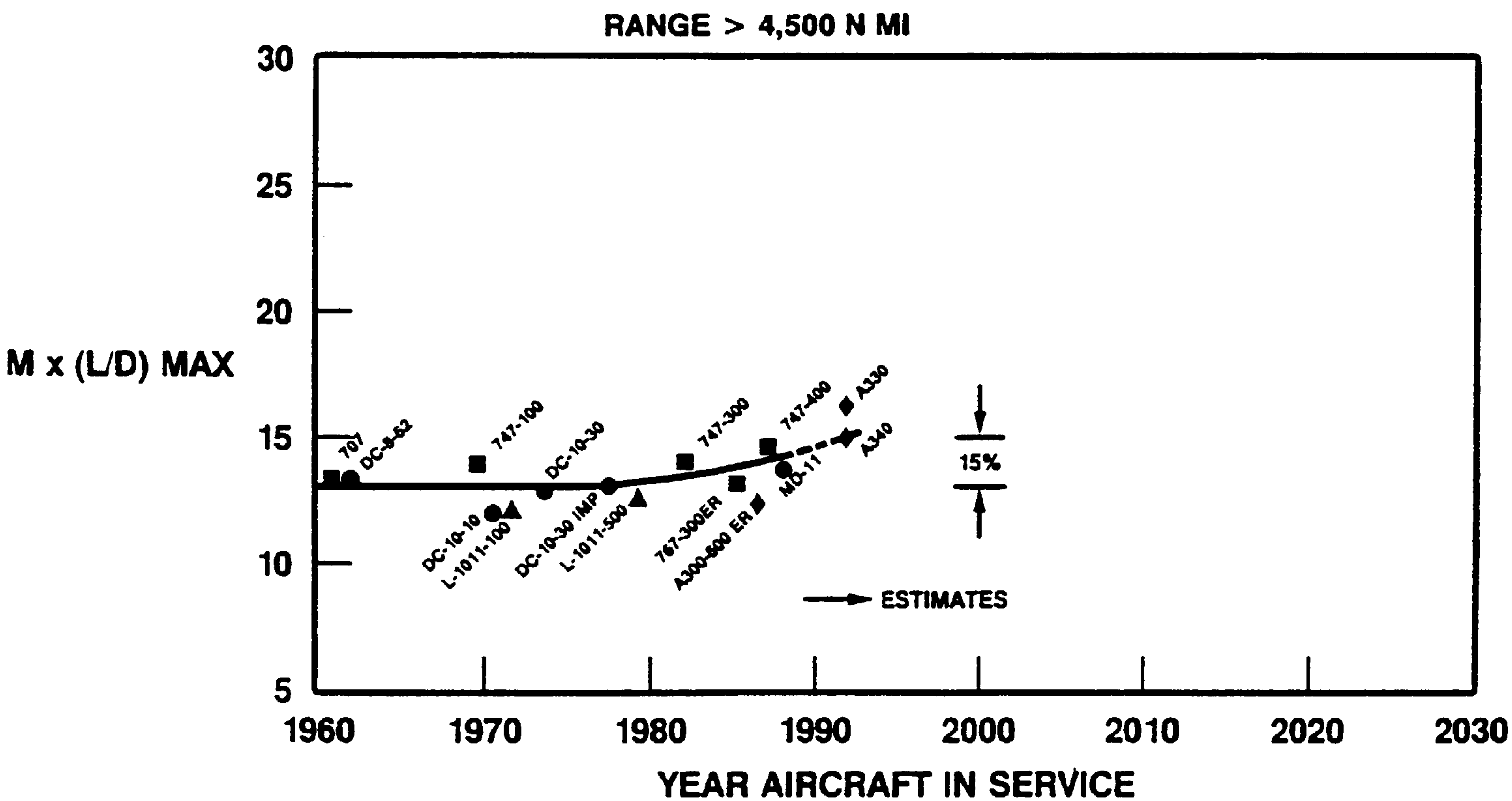
REALITY -- CIVILIAN AERONAUTICS

- Nominally a "mature"/"plateau" industry (for/with "current technology") <u>increasingly competitive</u> (Airbus, Asians, developing countries, etc.) <u>both economically and technologically</u>
- Difficult for America to compete on cost basis (labor rate issue)
- "Desperately seeking something" (NASA X-plane program)
  - Need to "surface"/create/work new/different technologies which can establish a new/higher "plateau"
    - GA
    - VTOL
    - CTOL
    - HSCT

FOR SUCCESS IN ECONOMIC WARFARE

Americans cannot work more cheaply than others (e.g., the Chinese), nor more dilligently than others (e.g., the Japanese), therefore, we must work more intelligently

Brandin/Harrison
"The Technology War"



AERODYNAMIC EFFICIENCY EVOLUTION OF LONG-RANGE TRANSPORT AIRPLANES

SUGGESTED AERO "HORIZON" MISSIONS

PART 1--<u>TRANSPORTS</u>

- Medium (450 pax max) and large (>600 pax) [different solution space in each size range]
- True "all-weather" flight capability
- Double L/D
- Half EW
- 10 db noise reduction
- Double $C_{L, MAX}$
- 1/2 number of parts
- 1/2 vortex hazard/spacing
- 50 percent reduction in initial/fuel/maintenance costs
- 75 percent reduction in emissions

- **A major design constraint for CTOL aircraft is L/D at takeoff**
  - **At takeoff, 90 percent of total drag is drag-due-to-lift**

From Paul Rubbert (Boeing)

TECHNIQUES FOR INDUCED DRAG REDUCTION

Technique	Category
• Increased wing aspect ratio	Planar vortex sheet
• Elliptical span loading	
• Spanwise/streamwise curvature	Non-planar vortex sheet
• Sheared wing tips	
• Serrated wing trailing edge	
• Wing tip turbines	Energy/thrust extraction from tip vortex
• Winglets	
• Vortex diffuser vanes	
• Wingtip sails	
• Wing tip engines	Alteration of wing tip boundary condition
• Porous wing tips	
• Wing tip blowing	
• Rotating cylinder at tip	
• Ring wing	"Elimination" of wing tips
• Joined wings/tails	
• Aft-mounted engines	Propulsion integration
• Over-wing blowing	

CTOL ADVANCED CONFIGURATION AERODYNAMICS

NEW WRINKLES ON OLD IDEAS, OR: IDEAS REEXAMINED IN TERMS OF TECHNOLOGY ADVANCES AND SYNERGISMS

- **Strut braced wings**
- **Double fuselage**
- **Bi-plane**

DRAG ADVANTAGES OF STRUT-BRACED WING

- Thinner wing sections
  - Higher drag-rise Mach number
  - Lower pressure drag

  reduced wing sweep

- Higher aspect ratio
  - Lower induced drag

- Allows tip engines for DDL reduction

- Enhanced laminar flow/LFC

"UPDATES" TO STRUT-BRACED WING CONCEPT

- Span reduced to FAA standard "80M box" for gate compatibility
- Wing tip engines for drag-due-to-lift and vortex hazard reduction
- Third engine in tail with thrust vectoring for engine out

Preserve/Keep:

- Strut-bracing utilized for reduced for wing thickness and sweep, greatly enhancing laminar flow

OPPORTUNITIES/APPROACHES SYNERGISTICALLY INTEGRATED PROPULSION AND AIRFRAME
(open thermodynamic system)

Approach	*Benefit*
• Wing tip engine	– 40%+ DDL red. (cruise) – Wake vortex hazard red.
• Circulation control wings	– Factor of 4+ increase in C_L – Reduced cost – Improved control/maneuverability
• Goldschmeid wing (suction for pressure recovery, inj. near TE)	– Up to 50% wing drag cancellation via static pressure thrust
• Boundary Layer Inlet	– Order of 10% to 20% increase in propulsion efficiency
• Thrust Vectoring	– Control
• HLFC Suction as Hi-lift L.E. Device	– Increased lift, red. cost
• Wing Tip Injection	– Red. DDL/ incr. L/D, red. vortex hazard
• Ejector wing	– Improved str./aero efficiency

‘UPDATES” TO DOUBLE FUSELAGE CONCEPT

- Advanced roll control
- Delete outer wing panels
- “Midwing” site of:
  - Landing gear
  - Engines (including B.L. injestion)
  - Pilot cabin
- Drag-due-to-lift and vortex hazard reduction
  - Fuselage/wing intersection/interaction tailoring
  - Empanage tailored to extract thrust from residual wing-induced fuselage vorticity
- Detachable/changeable fuselages to greatly improve duty cycle/ROI

BI-PLANE STATUS

(See paper by M. K. Zyskowski, N95-26956)

NOTE: Ring-wing should also be re-examined

- 25% cruise CD reduction compared to "equivalent" monoplane (primarily drag-due-to-lift reduction)
- 31% increase in L/D max

experimental results

- Significant additional drag reduction available via laminar flow control (reduced chord length, mitigates increased wing wetted area)
- Has improved pitching moment characteristics vis-a-vis monoplane
- Inately lower span, also reduced vortex hazard
- Up to 60% reduction in wing weight

IMPLICATIONS OF DRAG REDUCTION UPON HSCT PERFORMANCE

- **Fuel = 62% of gross takeoff weight including (8% reserves)**
- **Payload = 8% of gross takeoff weight**
- **1% drag reduction corresponds to order of**
  - -- 3,500 lb. empty weight reduction
  - -- 16,000 lb. takeoff weight reduction
  - -- 16 passenger payload increase
- **LFC over 1/2 of wing**
  - -- Reduces fuel weight equivalent to 1/2 of payload

SUPERSONIC DRAG REDUCTION
HOW LOW CAN YOU GO?

- Friction drag -- could be reduced 50-80% via laminar flow control

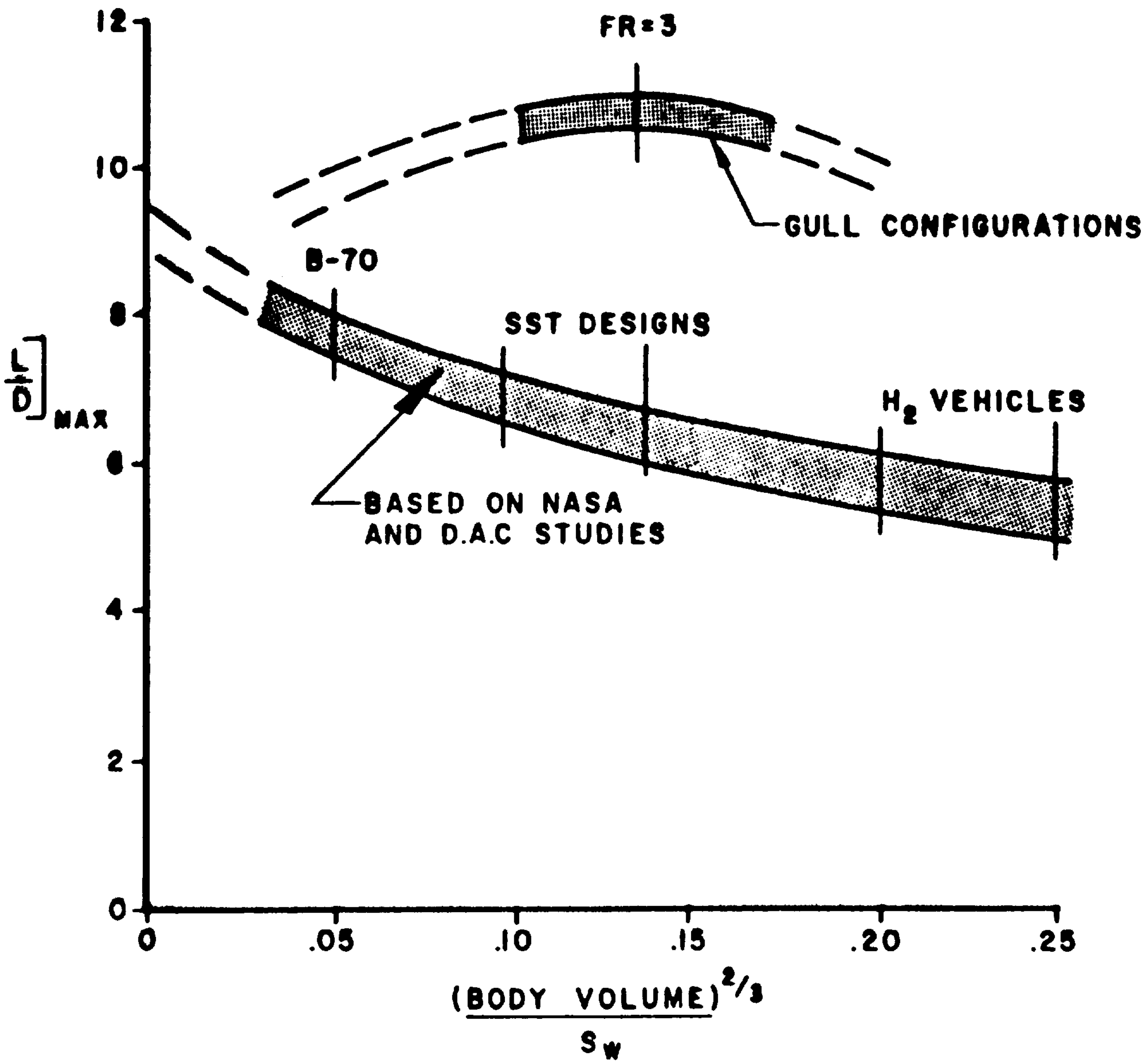
- Volume wave drag -- could be nearly eliminated by favorable shock wave interference

- Drag-due-to-lift -- arrow or yawed wing would minimize this drag component

EFFECT OF BODY VOLUME ON LIFT-DRAG RATIO

M = 3.0

RN ≈ 10^8 (TURBULENT)



BENEFITS/ISSUES--SUPERSONIC MULTI-BODY/FAVORABLE INTERFERENCE

BENEFITS

- Favorable interference wave drag reduction
- Reduced body Reynolds Number, enhanced laminar flow
- Thinner sections, reduced wave drag
- Improved structural efficiency

Multi-body

ISSUES

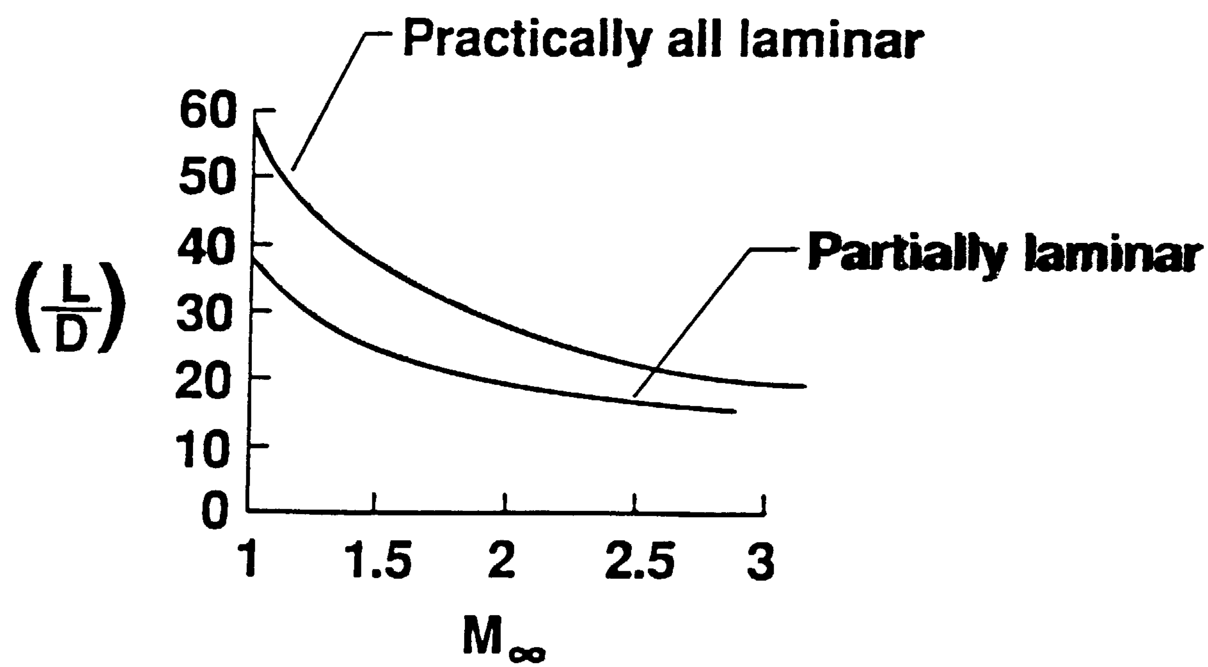
- "OFF design" (variable geometry/injection)
- Separation control for shock interaction regions
- Influence(s) upon sonic boom

FEATURES/ADVANTAGES

Pfenninger Strut-Braced Extreme Arrow HSCT Configuration

- **Minimum wave-drag-due-to-lift via extreme arrow planform (enabled by strut bracing)**
  - **Also increases aspect ratio/reduces vortex DDL**
- **Mid-wing fuel canisters utilized for favorable volume-induced wave interference and load alleviation**
- **Low wing Reynolds number favorable to extensive laminar flow**
- **"Natural" laminar flow on fuselage and mid-wing canisters**

SST WITH LFC AND HIGHLY SWEPT HIGH ASPECT RATIO STRUT-BRACED WING AND MULTIPLE BODIES



SUPERSONIC NATURAL LAMINAR FLOW

APPLICATIONS/CONFIGURATIONS

- **FUSELAGE** -- bluntness, heat strips, synthetic vision, aft wing/door placement

- **WINGS** -- (supersonic leading ledges, reduced x-flow)
  - Outboard sections, reduced wing/gross weight, improved low speed performance/lower drag
  - "Reverse" delta wing, improved low speed performance/lower drag

OPTIONS FOR MULTISTAGE AIRCRAFT

- Separate subsonic takeoff and landing carrier A/C (e.g., 747, Roskam)
- Flyback integrated stage to accommodate the fuel weight/noise/high lift/heavy gear conditions unique to takeoff
- In-flight refueling
- Takeoff assistance
  - Ski jumps on takeoff runways
  - Ground trolleys
  - Etc. (laser-guided water jets)

SUMMARY

SAMPLE POSSIBILITIES FOR REVOLUTIONAL AERODYNAMIC PERFORMANCE IMPROVEMENTS

Subsonic/CTOL Transports

- **End-point "conventional" design**
  - **Extensive laminar flow**
  - **Large aspect ratio or tip engines (via strut bracing) for DDL reduction**
- **Double fuselage mid-wing, ring wing/biplane**
- **Synergistic combinations (spanloaders)**
  - **Load-carrying**
  - **Lifting surfaces**
  - **Propulsion**

  plus laminar flow control

Supersonic/HSCT Transports

- **Spanloader oblique wing** ($M \approx 1.6$)
- **Favorable wave interference**
- **Extreme arrow wing via strut bracing/load alleviation**

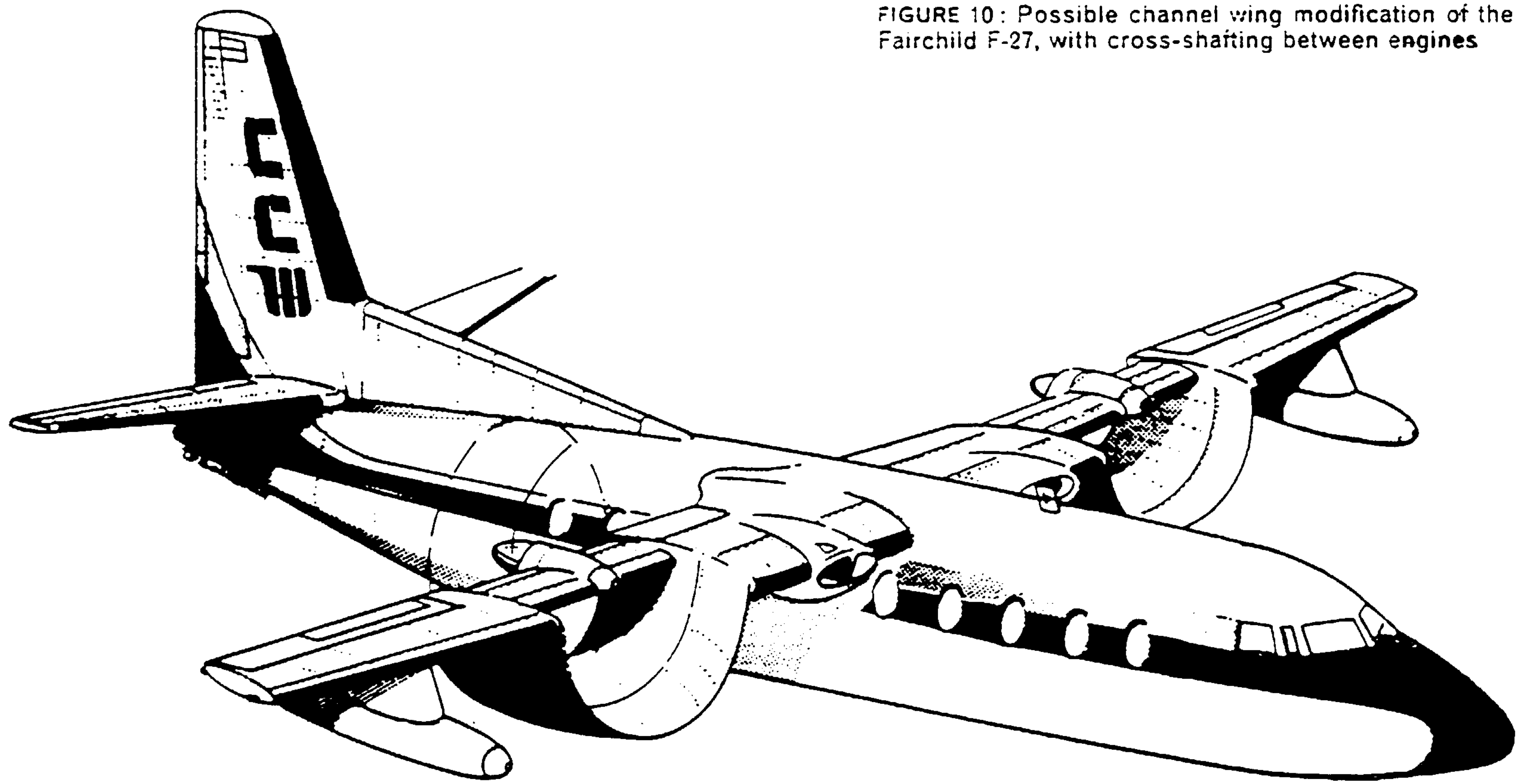


FIGURE 10: Possible channel wing modification of the Fairchild F-27, with cross-shafting between engines

PROSPECTIVE CHANNEL WING V/STOL PERFORMANCE IMPROVEMENT OPPORTUNITIES *(Combination of Powered Lift and Power-Induced Aerodynamic Lift)*

- **Circulation control (increase lbs. of lift/H.P.)**
- **Separation control (improve channel performance)**
- **Laminar flow control (for cruise performance)**
- **Strut-bracing (decreased DDL, weight)**

OPPORTUNITIES SUMMARY
ADVANCED CONCEPT PROPULSION

APPROACH	APPLICATION
• Ceramic wankel (Mollar)	• VTOL converticar, GA, RPV
• Pulse detonation wave cycle	• Rocket, air-breathing (space access, HSCT, CTOL)
• Lithium-air engines (fuel cells)	• HALE (ersatz satellite capability), VTOL, GA
• Advanced hypersonic cycles (pre-mixed/shock enhanced combustion, liquid air cycles with advanced separation technology, RBCC endothermic hydrocarbon fuels)	• Space access, cruise
• Endothermic fuel-cooled gas turbine engines	• CTOL, HSCT

ADVANCED CONFIGURATION RESEARCH MATRIX

Discipline Elements (and their interactions)		Figures of Merit		Configuration Possibilities		Sample Technologies
• Systems • Aerodynamics • Acoustics • Propulsion • Structures • Materials • Controls/ Electronics • Human Factors	X	• Costs -Development -Life cycle • Aero efficiency -L/D, Hi-lift • Emissions (Ozone, Greenhouse) • Propulsion efficiency • Structural efficiency • Airport productivity -Acoustics -"All weather" -Hi-lift • Safety	X	**CTOL** • Double fuselage/mid wing • Strut-braced A/C • Blended-wing bodies/ spanloaders • Ring wing/biplane **HSCT** • Oblique wings • Supersonic leading edges/ HLFC • Favorable wave interference • Strut-braced extreme arrow wing • Multi-stage A/C -Fly-back -Takeoff assist	X	• Fuel cooling • Brilliant structures • LFC/HLFC • Circul. control • Flow separation control (incl. cruise) • DDL red. • Strut bracing • Electronics/MEMS • Vortex control • Free mixing control • Turbulent drag red. • Thrust vectoring • Variable geometry • Propulsive-aero favorable interaction •PDW engines

(CONVENTIONAL) AIRCRAFT VERSUS SHIP FOR "STRATEGIC MOBILITY"

Aircraft has:

- 10X speed
- 1/100 cargo capacity
- Approximately same construction cost 0($200M+)

CIRCUMVENTION APPROACHES FOR (DISPLACEMENT HULL) SURFACE WAVE DRAG

- Submarine
- Swath Ship
- Planing Hull
- Hydrofoils
- Surface Effect Aircraft

"Submerged"

"Airborne"

"100+ KNOT SHIP"
(Prospective Features)

- "Swath-Like"
  - Surface-piercing struts allow favorable interference for wave drag reduction
  - Contour upper works for aero drag reduction
  - (Residual) drag problem on buoyancy hulls
- Drag Reduction on "Swath" Buoyancy Hulls
  - Goldschmied/pressure-thrust stern(s)
  - Skin friction drag reduction via one or more of the following
    - On-board cultured polymer (feedstock = phytoplankton filtered from cooling water)
    - Surface boiling
    - Supercavitation
    - E-M turb control
    - Downstream translating walls
  - Smooth(er) surfaces for roughness drag reduction, ("natural" anti-fouling)
  - Nose "swords" (ala Kiev research)

SUGGESTED AERO "HORIZON" MISSIONS

PERSONAL AIRCRAFT

- Affordable ($\approx$ 30K+, in quantity production)
- Safe
- VTOL
- "Converticar"
- 4 person, $\approx$ 2000 lbs. EW
- FULLY AUTOMATIC (NAV., ATC., OPS.)
- Acceptable acoustics/maintenance
- "All weather"
- Helo or vectored lift-fan
- At least 160 kn. cruise
- Should significently reduce capital costs of long distance highways

ADVANTAGES OF PERSONAL HELICOPTER VIS-A-VIS PRESENT AUTO

- Faster (200 MPH$^+$ vs. 40 MPH (in traffic) for approximately same size/cost
- Fully automatic operation
  - Vastly improved safety (operator error major cause of accidents)
  - Allows transport of the infirm and inebriated
- Allows more even distribution of population over much wider area
- Allows more personal (a) "elbow room," (b) privacy, (c) freedom of choice, and (d) "action radius"
- Reduces usage of CTOL airports for short/medium trips
- Scheduled arrival times (through automatic operation/ATC)
- Allows cost savings due to reduced need for
  - Highways
  - Bridges
- Revolutionizes transport industry (1/5 of GNP), provides excellent escape method for fire in high rise buildings

EMERGING KEY INGREDIENTS OF AN AFFORDABLE AUTOMATIC SYSTEM

- Civilian utilization of high resolution GPS (inexpensive, accurate)
- Personal satellite commun. systems (inexpensive, real-time global coverage)
- Extensive AAV/UAV/RPV/UTA (primarily military-developed) technology (inexpensive, fault-tolerant controls/communication software/sensors, etc.)

SUMMARY

There are multitudinous "different" concepts available which appear to offer revolutionary improvements in all metrics in the various mission arenas

- -- Personal aircraft
- -- Subsonic long haul
- -- HSCT
- -- V/STOL

- These concepts require extensive evaluation and optimization to determine both technical and market reality/feasibility
- Such research is required to provide a renaissance in/ensure continued viability of U.S. civilian aviation industry